CHAPTER 4: OFFSITE CONSEQUENCE ANALYSIS

You are required to conduct an offsite consequence analysis to provide information to the government and the public about the potential consequences of an accidental chemical release. The offsite consequence analysis (OCA) consists of two elements:

- A worst-case release scenario and
- Alternative release scenarios.

To simplify the analysis and ensure a common basis for comparisons, EPA has defined the worst-case scenario as the release of the largest quantity of a regulated substance from a single vessel or process line failure that results in the greatest distance to an endpoint. In broad terms, the distance to the endpoint is the distance an ammonia vapor cloud will travel before dissipating to the point that serious injuries from short-term exposures will no longer occur.

This chapter gives guidance on how to perform the offsite consequence analysis for anhydrous ammonia in ammonia refrigeration facilities. Exhibit 4-1 shows the basic steps used to conduct the OCA.

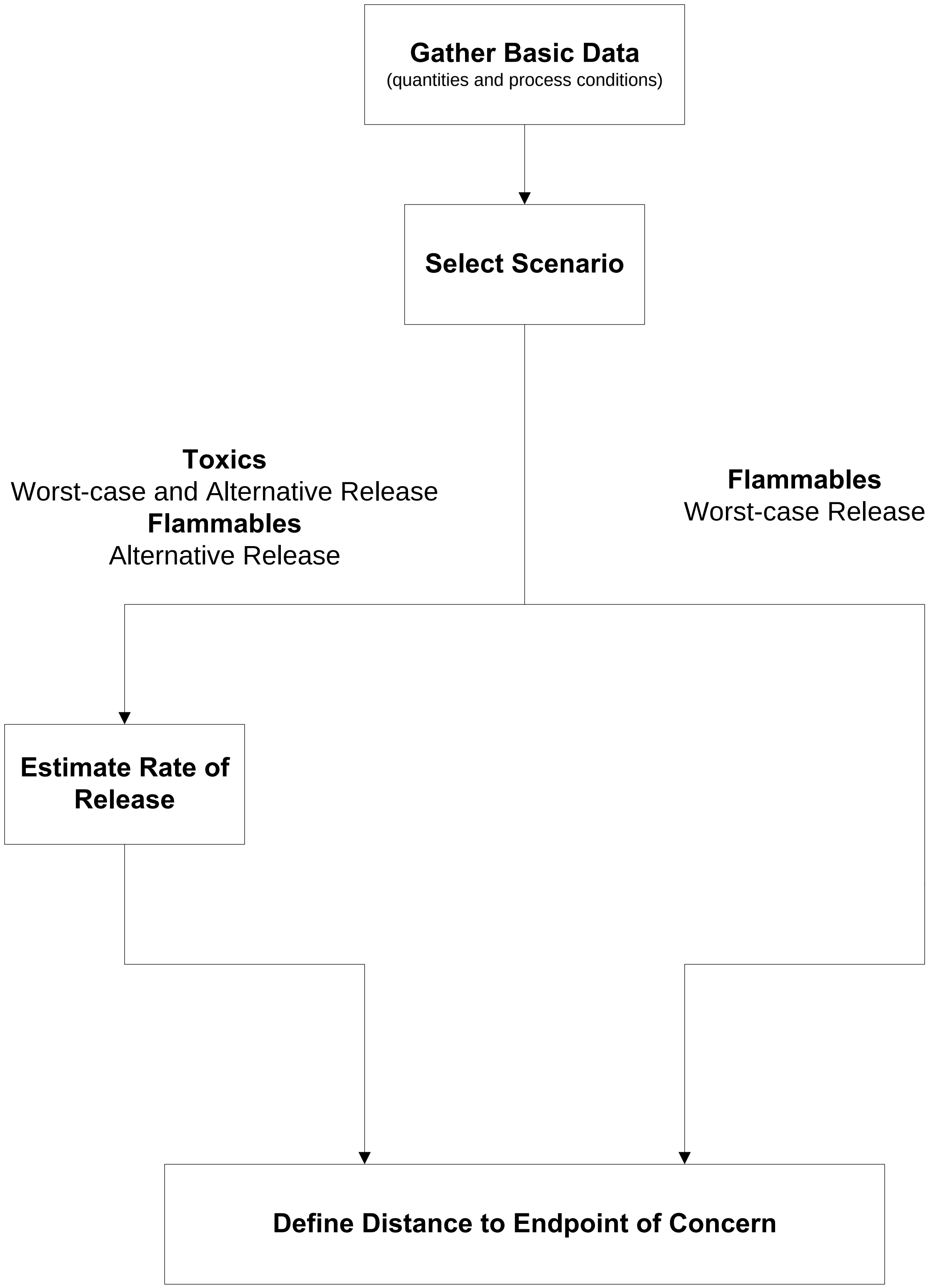
RMP*Comp™

To assist those using this guidance, the National Oceanic and Atmospheric Administration (NOAA) and EPA have developed a software program, RMP*Comp™, that performs the calculations described in this document. This software can be downloaded from the EPA Internet website at http://www.epa.gov/swercepp/tools/rmp-comp/rmp-comp.html.

You are not required to use this guidance. You may use publicly available or proprietary air dispersion models to do your offsite consequence analysis, subject to certain conditions. If you choose to use other models, you should review the rule and Chapter 4 of the *General Guidance for Risk Management Programs*, which outline required conditions for use of other models.

Complex models that can account for many site-specific factors may give less conservative estimates of offsite consequences than the simple methods in this guidance. This is particularly true for alternative scenarios, for which EPA has not specified many assumptions. However, complex models may be expensive and require considerable expertise to use; this guidance is designed to be simple and straightforward. You will need to consider these tradeoffs in deciding how to carry out your required consequence analyses.

EXHIBIT 4-1
STEPS FOR OFFSITE CONSEQUENCE ANALYSIS



This chapter presents discussions and tables for the worst-case scenario (section 4.1), followed by discussions and tables for alternative scenarios (section 4.2). The remaining sections provide guidance on defining offsite impacts (section 4.3), and documentation (section 4.4).

The guidance presented in this chapter is intended for users — that is, it does not contain explanations of how the guidance was derived. For those readers who are interested in following this up, there is a document entitled *Backup Information for the Hazard Assessments in the RMP Offsite Consequence Analysis Guidance, the Guidance for Wastewater Treatment Facilities and the Guidance for Ammonia Refrigeration—Anhydrous Ammonia, Aqueous Ammonia, Chlorine and Sulfur Dioxide*. This Backup Document is available from EPA.

4.1 WORST-CASE RELEASE SCENARIO ANALYSIS (§ 68.25)

Exhibit 4-2 presents the parameters that must be used in analyzing the worst-case and alternative release scenarios.

MANDATORY INPUT

The following input is required by the Risk Management Program rule:

- The worst-case release quantity Q (lb) shall be the greater of the following:
  - For substances in a vessel, the greatest amount held in a vessel, taking into account administrative controls that limit the maximum quantity; or
  - For substances in pipes, the greatest amount in a pipe, taking into account administrative controls that limit the maximum quantity.

For ammonia refrigeration systems, a storage vessel or high-pressure receiver is likely to contain the largest quantity. (See Appendix 4A to this Chapter for a description of ammonia systems.)

- Because ammonia is a vapor at ambient temperature and is handled as a liquid under pressure in most parts of a refrigeration system, the quantity Q is completely released from the vessel over a period of 10 minutes. This applies whether the release takes place outside or in a building.
- *Weather conditions.* The rule specifically allows anyone who conducts their OCA based on this guidance to use specific default weather conditions for wind speed, stability class, average temperature, and humidity.

EXHIBIT 4-2
REQUIRED PARAMETERS FOR MODELING AMMONIA (40 CFR 68.22)

WORST CASE	ALTERNATIVE SCENARIO
Endpoints (§68.22(a))	
Toxic endpoints are listed in part 68 Appendix A.	Toxic endpoints are listed in part 68 Appendix A.
Wind speed/stability (§68.22(b))	
This guidance assumes 1.5 meters per second and F stability. For other models, use wind speed of 1.5 meters per second and F stability class unless you can demonstrate that local meteorological data applicable to the site show a higher minimum wind speed or less stable atmosphere at all times during the previous three years. If you can so demonstrate, these minimums may be used for site-specific modeling.	This guidance assumes wind speed of 3 meters per second and D stability. For other models, you must use typical meteorological conditions for your site.
Ambient temperature/humidity (§68.22(c))	
This guidance assumes 25EC (77EF) and 50 percent humidity. For other models for toxic substances, you must use the highest daily maximum temperature and average humidity for the site during the past three years.	This guidance assumes 25EC and 50 percent humidity. For other models, you may use average temperature/humidity data gathered at the site or at a local meteorological station.
Height of release (§68.22(d))	
For toxic substances, you must assume a ground level release.	This guidance assumes a ground-level release. For other models, release height may be determined by the release scenario.
Surface roughness (§68.22(e))	
Use urban (obstructed terrain) or rural (flat terrain) topography, as appropriate.	Use urban (obstructed terrain) or rural (flat terrain) topography, as appropriate.
Dense or neutrally buoyant gases (§68.22(f))	
Tables or models used for dispersion of regulated toxic substances must appropriately account for gas density.	Tables or models used for dispersion must appropriately account for gas density.
Temperature of released substance (§68.22(g))	
You must consider liquids (other than gases liquefied by refrigeration) to be released at the highest daily maximum temperature, from data for the previous three years, or at process temperature, whichever is higher. Assume gases liquefied by refrigeration at atmospheric pressure to be released at their boiling points.	Substances may be considered to be released at a process or ambient temperature that is appropriate for the scenario.

If you do your own modeling, you can obtain weather data from local weather stations. You can also obtain temperature and wind speed data from the National Climatic Data Center at (828) 271-4800.

- For the worst-case scenario, the release must be assumed to take place at *ground level*.

- The toxic endpoint for ammonia is 200 ppm (0.14 mg/L). This airborne concentration is the maximum airborne concentration below which it is believed that nearly all individuals can be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

QUANTITY RELEASED AND RELEASE RATE IN THE WORST-CASE RELEASE SCENARIO

QUANTITY RELEASED

Take the largest quantity Q (lb) of ammonia that is liquefied under pressure in any vessel in the ammonia refrigeration system. For many systems, this vessel will be the high pressure receiver with typical pressures in the range 100 to 200 psig. Other candidate vessels include:

- An outside vessel in which ammonia is stored as a liquid at ambient temperature (some, but not all, facilities have such a vessel);

- An intermediate receiver with typical pressures in the range 20 to 60 psig (typical of two-stage ammonia refrigeration systems); or

- A low-pressure receiver with pressures in the range 10-60 psig (typical of single-stage refrigeration systems).

In the case of a vessel, the quantity *does not* include any liquid ammonia in pipework connected to the vessel and in any other vessel that can discharge directly into pipework connected to the vessel. However, the maximum amount of ammonia that could be in the vessel at any one time, not just during normal operation, should be considered. For example, if the vessel is used to store some or all of the ammonia while the rest of the system is being serviced, then Q should include the additional quantity of ammonia that is in the vessel at such a time. If there are administrative controls that limit the amount of ammonia that is allowed in the vessel at any one time, this limit can also be taken into account when estimating Q. Similarly, if the largest quantity is in a pipeline, you do not need to consider the quantity of ammonia in connected vessels.

RELEASE RATE

Unmitigated Releases. For the worst-case scenario for a substance that is a gas under ambient conditions, the largest vessel is assumed to fail in a catastrophic manner, and the release occurs over a period of 10 minutes. The worst-case release rate is:

$$QR = Q/10 \tag{1}$$

where: QR = Release rate (lbs/min)
Q = Quantity released (lbs)

The rapid release of ammonia initially liquefied under pressure leads to an airborne mixture of vapor and droplets. If the vessel is outdoors, all of the vapor and droplets remain airborne, and the release rate (QR) is the total inventory uniformly distributed over 10 minutes, as required by the rule.

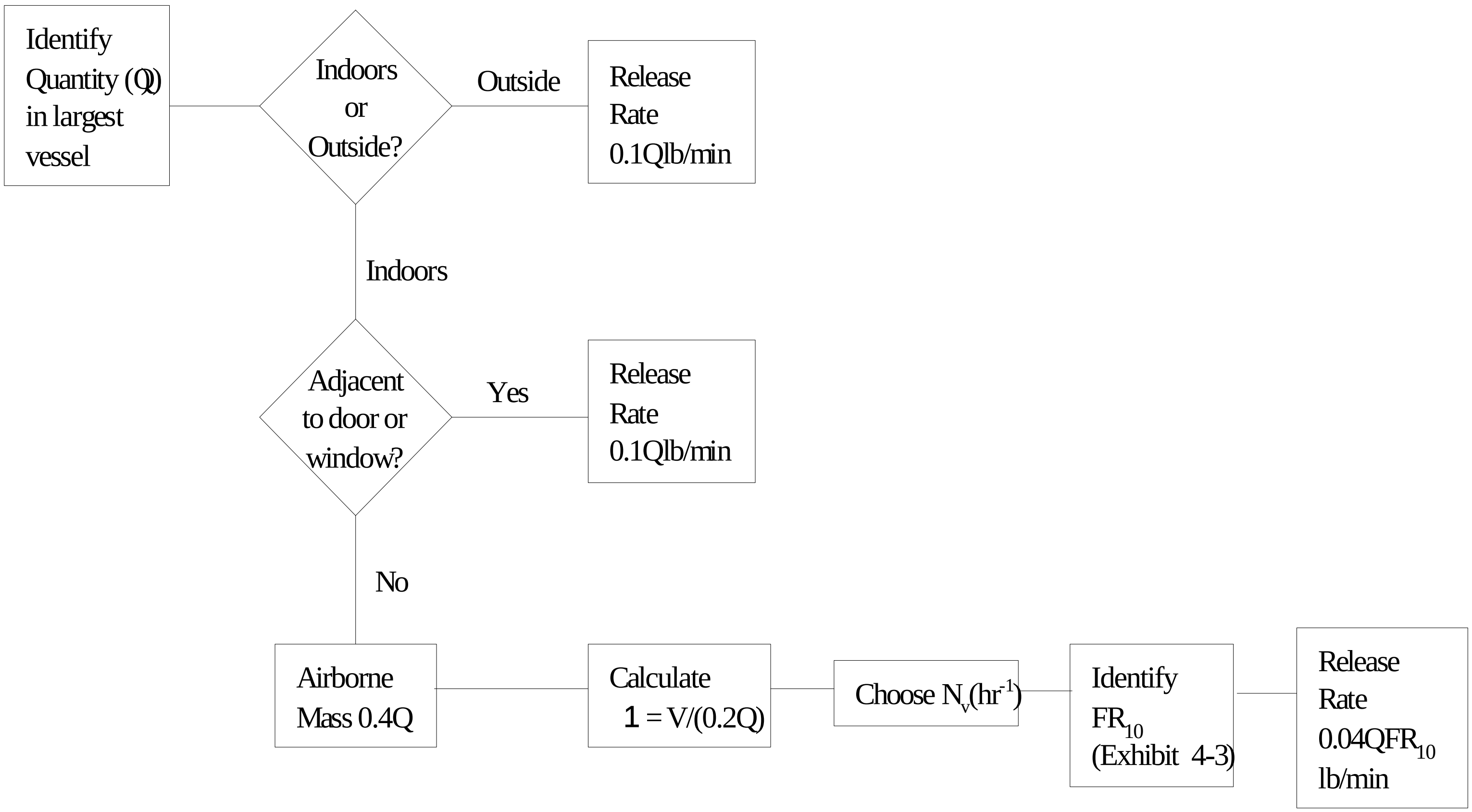
Mitigated Releases. The rule allows you to consider passive mitigation in estimating the worst-case release rate. Figure 4-1 displays the procedure to be followed to determine the release rate for the worst-case scenario. If the release takes place in a building, the building can be considered to provide passive mitigation, unless:

- The building may fail as a result of the release. This is unlikely except in the case of a large vessel in a very small room. As a rough rule of thumb, if the room volume (V) divided by the quantity of ammonia (Q) in the vessel is less than 0.1 ft^3/lb, you should look at the possibility that the release of ammonia will cause failures such as windows blowing out or doors blowing open.

- The release takes place facing an opening in the building (door or window). In this case, you should assume that the door or window will be open, and the ammonia will be released through these openings.

If the building may fail as a result of the release, estimate the release rate as for an unmitigated release (Equation 1, QR = Q/10 lb/min). Similarly, if the release would take place facing doors or windows, the release rate is again the entire inventory uniformly distributed over 10 minutes (Equation 1).

Figure 4-1. Guidance on Effectiveness of Building Mitigation for Worst-Case Scenarios



If the above conditions do not apply, you can assume that rain-out of liquid droplets is facilitated by impingement on surfaces (in a compressor room, for example), and only a portion of the released material will become airborne. The remainder collects in relatively slowly evaporating pools and makes only a small contribution to the rate of release from the building. To estimate the mitigated release rate, assume the following:

- The amount of material airborne in the building is four-tenths of the total inventory, or 0.4 Q.

- The airborne material includes 0.2 Q vapor and 0.2 Q liquid droplets.

Exhibit 4-3 provides factors for estimating the mitigated release rate from a building. To estimate the release rate using these factors, do the following:

- Estimate 1 as follows:

  - Determine room volume, V, in ft^3

  - Calculate 1 from room volume divided by the quantity of ammonia initially released as vapor, or

    1 (ft^3/lb) = V/(0.2 Q)

- Determine the active ventilation rate, N_v, in room volumes exchanged per hour (hr^{-1}), for the building.

- From Exhibit 4-3, find the 10-minute building attenuation factor, FR_{10}, corresponding to your estimated 1 and the ventilation rate, N_v.

- Estimate the release rate in lbs/min from the building attenuation factor and the airborne quantity (0.4 Q) as follows, assuming the release takes place over 10 minutes:

$$QR_B = (FR_{10} \times 0.4Q)/10 \qquad (2)$$

Example 1 A high-pressure receiver containing 5,000 lb of ammonia is in a room of dimensions 20 feet x 50 feet x 30 feet = 30,000 ft^3. Hence, 1 = 30,000/(5,000 x 0.2) = 30 ft^3/lb. The nearest value of 1 on Exhibit 4-3 is 1 = 25. The ventilation rate for the building is 5 hr^{--1}. For 1 = 25 and N_v = 5, FR_{10} = 0.35, and the release rate to the atmosphere is QR_B = (0.35)(0.4)(5,000)/10 = 70 lb/min, using Equation 2 above.

EXHIBIT 4-3
TEN-MINUTE BUILDING RELEASE ATTENUATION FACTORS FOR PROLONGED RELEASES

1 **(ft^3/lb)**	**N_v** **(hr^{-1})**	**FR_{10}** **(dim)**		**1** **(ft^3/lb)**	**N_v** **(hr^{-1})**	**FR_{10}** **(dim)**
150.0	0	0.07		10.0	0	0.61
	1	0.08			1	0.61
	5	0.32			5	0.61
	10	0.51			10	0.61
	20	0.71			20	0.71
	30	0.80			30	0.80
	40	0.85			40	0.85
100.0	0	0.11		5.0	0	0.79
	1	0.11			1	0.79
	5	0.32			5	0.79
	10	0.51			10	0.79
	20	0.71			20	0.79
	30	0.80			30	0.80
	40	0.85			40	0.85
50.0	0	0.20		1.0	0	0.96
	1	0.20			1	0.96
	5	0.32			5	0.96
	10	0.51			10	0.96
	20	0.71			20	0.96
	30	0.80			30	0.96
	40	0.85			40	0.96
25.0	0	0.35		0.5	0	0.98
	1	0.35			1	0.98
	5	0.35			5	0.98
	10	0.51			10	0.98
	20	0.71			20	0.98
	30	0.80			30	0.98
	40	0.85			40	0.98

Example 2 The 5,000 lb vessel in Example 1 is outside. The release rate is, therefore, QR = 5,000/10 = 500 lb/min. It can be seen that the building provides extensive attenuation. However, to take advantage of this potential attenuation, you must be certain that the worst-case scenario cannot occur outside or adjacent to a door or window that may be open.

OTHER POTENTIAL WORST-CASE SCENARIOS

The rule requires that you look for other potential scenarios that could affect offsite populations further away from the site or in different areas than does the release from the largest vessel. Thus, even if an outside storage vessel is smaller than your high-pressure receiver, you should consider the release of its contents over a 10-minute period as a possible worst-case scenario. Similarly, if a pipe containing ammonia liquefied under pressure is outside for part of its length, you should consider the release of the contents of that pipe as a possible worst-case scenario.

DISTANCE TO THE TOXIC ENDPOINT

Take the estimated worst-case rate of release QR (unmitigated) or QR_B (in a building) and go to Exhibit 4-4. Find the entry in the "Rate of Release" column that is closest to your estimated release rate. Read off the corresponding distance from the urban or the rural column. This is the "distance to the endpoint" that must be submitted (in miles) in the RMP information.

To decide whether the site is rural or urban, the rule gives the following guidance in § 68.22(e): "Urban means that there are many obstacles in the immediate area; obstacles include buildings or trees. Rural means that there are no buildings in the immediate area and the terrain is generally flat and unobstructed."

Figure 4-2 represents Exhibit 4-4 in graphical form. Both apply to releases of duration 10 minutes.

Example 3 Take the 500 lb/min release rate from Example 2. From Exhibit 4-4, the predicted distance to the toxic endpoint is ~ 1.3 miles at a rural site and ~ 0.9 miles at an urban site. For the 70 lb/min release of Example 1, these distances become 0.5 miles and 0.3 miles, respectively.

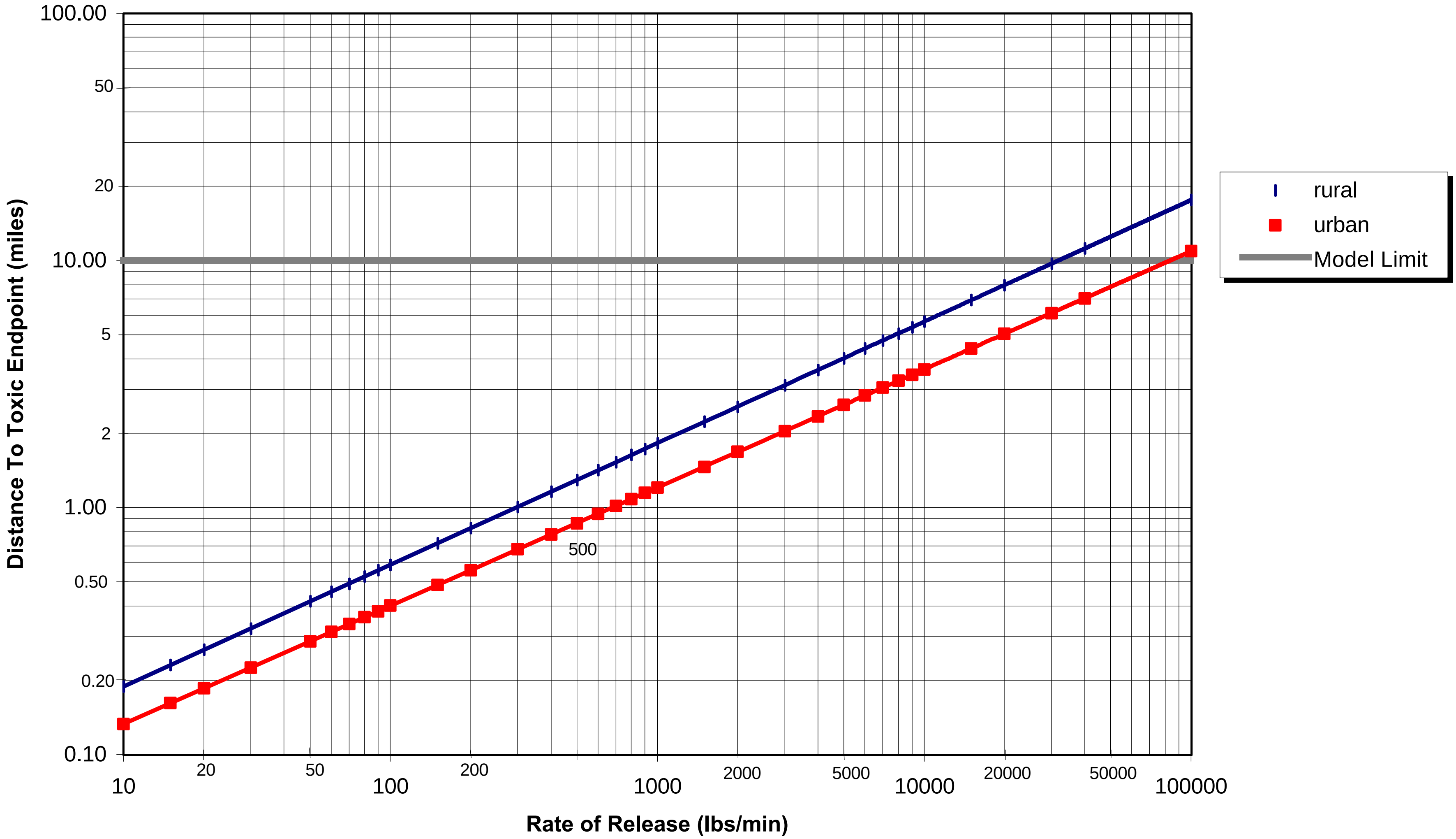
EXHIBIT 4-4
DISTANCES TO TOXIC ENDPOINT
FOR ANHYDROUS AMMONIA LIQUEFIED UNDER PRESSURE
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	0.1	0.1
2	0.1	0.1
5	0.1	0.1
10	0.2	0.1
15	0.2	0.2
20	0.3	0.2
30	0.3	0.2
40	0.4	0.3
50	0.4	0.3
60	0.5	0.3
70	0.5	0.3
80	0.5	0.4
90	0.6	0.4
100	0.6	0.4
150	0.7	0.5
200	0.8	0.6
250	0.9	0.6
300	1.0	0.7
400	1.2	0.8
500	1.3	0.9
600	1.4	0.9
700	1.5	1.0
750	1.6	1.0
800	1.6	1.1
900	1.7	1.2

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1,000	1.8	1.2
1,500	2.2	1.5
2,000	2.6	1.7
2,500	2.9	1.9
3,000	3.1	2.0
4,000	3.6	2.3
5,000	4.0	2.6
6,000	4.4	2.8
7,000	4.7	3.1
7,500	4.9	3.2
8,000	5.1	3.3
9,000	5.4	3.4
10,000	5.6	3.6
15,000	6.9	4.4
20,000	8.0	5.0
25,000	8.9	5.6
30,000	9.7	6.1
40,000	11	7.0
50,000	12	7.8
75,000	15	9.5
100,000	18	10
150,000	22	13
200,000	*	15
250,000	*	17
750,000	*	*

* More than 25 miles (report distance as 25 miles)

Figure 4-2 Worst-Case Scenario - Predicted Distances to Toxic Endpoint
Anhydrous Ammonia @ Atmospheric Stability Class F with Windspeed 1.5 m/s



4.2 ALTERNATIVE RELEASE SCENARIO

The owner or operator must identify and analyze at least one "alternative" release scenario.

CHOICE OF THE ALTERNATIVE SCENARIO

Your alternative scenario for a covered process must be one that is more likely to occur than the worst-case scenario and that reaches an endpoint offsite, unless no such scenario exists. Note that this requirement means that the release rate for the alternative scenario for ammonia must be fairly large, or it generally will not reach the ammonia endpoint offsite. You do not need to demonstrate greater likelihood of occurrence or carry out any analysis of probability of occurrence; you only need to use reasonable judgement and knowledge of the process. If, using a combination of reasonable assumptions, modeling of a release of a regulated substance from a process shows that the relevant endpoint is not reached offsite, you can use the modeling results to demonstrate that a scenario does not exist for the process that will give an endpoint offsite. You must report an alternative scenario, however. Release scenarios you should consider include, but are not limited to, the following, where applicable:

- Transfer hose releases due to splits or sudden uncoupling;
- Process piping releases from failures at flanges, joints, welds, valves and valve seals, and drains or bleeds;
- Process vessel or pump releases due to cracks, seal failure, drain bleed, or plug failure;
- Vessel overfilling and spill, or overpressurization and venting through relief valves or rupture disks; and
- Shipping container mishandling and breakage or puncturing leading to a spill.

For alternative release scenarios, you may consider active mitigation systems, such as interlocks, shutdown systems, pressure relieving devices, flares, emergency isolation systems, and fire water and deluge systems, as well as passive mitigation systems. Mitigation systems considered must be capable of withstanding the event that triggers the release while remaining functional.

You must consider your five-year accident history and failure scenarios identified in your hazard review or process hazards analysis in selecting alternative release scenarios for regulated toxic or flammable substances (e.g., you might choose an actual event from your accident history as the basis of your scenario). You also may consider any other reasonable scenarios.

The alternative scenarios you choose to analyze should be scenarios that you consider possible at your site. Although EPA requires no explanation of your choice of scenario, you should choose a scenario that you think you can explain to emergency responders and the public as a reasonable alternative to the worst-case scenario. For example, you could pick a scenario based on an actual event, or you could choose a scenario that you worry about, because circumstances at your site might make it a possibility. If you believe that there is no reasonable scenario that could lead to offsite consequences, you may use a scenario that has no offsite impacts for your alternative analysis. You should be prepared to explain your choice of such a scenario to the public, should questions arise.

Appendix E of this guidance is a hazard alert for ammonia releases at ammonia refrigeration facilities. This alert includes a discussion of accidents that have occurred in the past at such facilities. The information on past accidents may be helpful to you in developing a reasonable alternative scenario for your facility.

ALTERNATIVE SCENARIOS FOR AMMONIA AT REFRIGERATION FACILITIES

For the alternative scenario analysis, you should use typical meteorological conditions for your site. This guidance uses an "average" weather condition of wind speed 3 m/s and D stability class with an ambient temperature of 25 ^{o}C. If these are not reasonable conditions for your site, you may want to use other methods to analyze alternative scenarios. You may obtain meteorological data from local weather stations. You can obtain wind speed and temperature data from the National Climatic Data Center at (828) 271-4800.

For the alternative scenario analysis, you need to estimate the release rate of ammonia and the distance to the toxic endpoint. Exhibit 4-5 and Figure 4-3 provide distances to the endpoint for a range of release rates under the weather conditions discussed above. Note that Exhibit 4-5 and Figure 4-3 (and Equations B-3 and B-4 in Appendix 4B) are intended to apply to releases of any duration.

For the purposes of the present guidance, a simple alternative scenario has been chosen: an outdoor release through a hole in a tank or pipe containing ammonia liquefied under pressure, leading to an airborne release. For the release of liquid, you can estimate the release rate from the Bernoulli Equation; for ammonia liquefied under pressure, you can assume the liquid vaporizes immediately, and the release rate of the liquid is the same as the release rate to air. The following is a simplified version of the Bernoulli Equation, incorporating chemical-specific factors for ammonia:

$$QR = HA \times (203)(P_g)^{1/2} \tag{3}$$

where: QR = Release rate (pounds per minute)
HA = Hole area (square inches)
P_g = Gauge pressure (psig)

See Appendix 4B for a discussion of the Bernoulli Equation and the derivation of the simplified equation above.

EXHIBIT 4-5
DISTANCES TO TOXIC ENDPOINT FOR ANHYDROUS AMMONIA
D Stability, Wind Speed 3 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
<10	0.1	0.1
10	0.1	
15	0.1	
20	0.1	
30	0.1	
40	0.1	
50	0.1	
60	0.2	0.1
70	0.2	0.1
80	0.2	0.1
90	0.2	0.1
100	0.2	0.1
150	0.2	0.1
200	0.3	0.1
250	0.3	0.1
300	0.3	0.1
400	0.4	0.2
500	0.4	0.2
600	0.5	0.2
700	0.5	0.2
750	0.5	0.2
800	0.5	0.2
900	0.6	0.2
1,000	0.6	0.2
1,500	0.7	0.3
2,000	0.8	0.3
2,500	0.9	0.3
3,000	1.0	0.4
4,000	1.2	0.4
5,000	1.3	0.5
7,500	1.6	0.5
10,000	1.8	0.6
15,000	2.2	0.7
20,000	2.5	0.8
25,000	2.8	0.9
30,000	3.1	1.0
40,000	3.5	1.1
50,000	3.9	1.2
75,000	4.8	1.4
100,000	5.4	1.6
150,000	6.6	1.9
200,000	7.6	2.1
250,000	8.4	2.3
300,000	9.2	2.5

Figure 4-3 Alternative Case Scenario - Predicted Distances To Toxic Endpoint For Anhydrous Ammonia @ Atmospheric Stability Class D with Windspeed 1.5 m/s

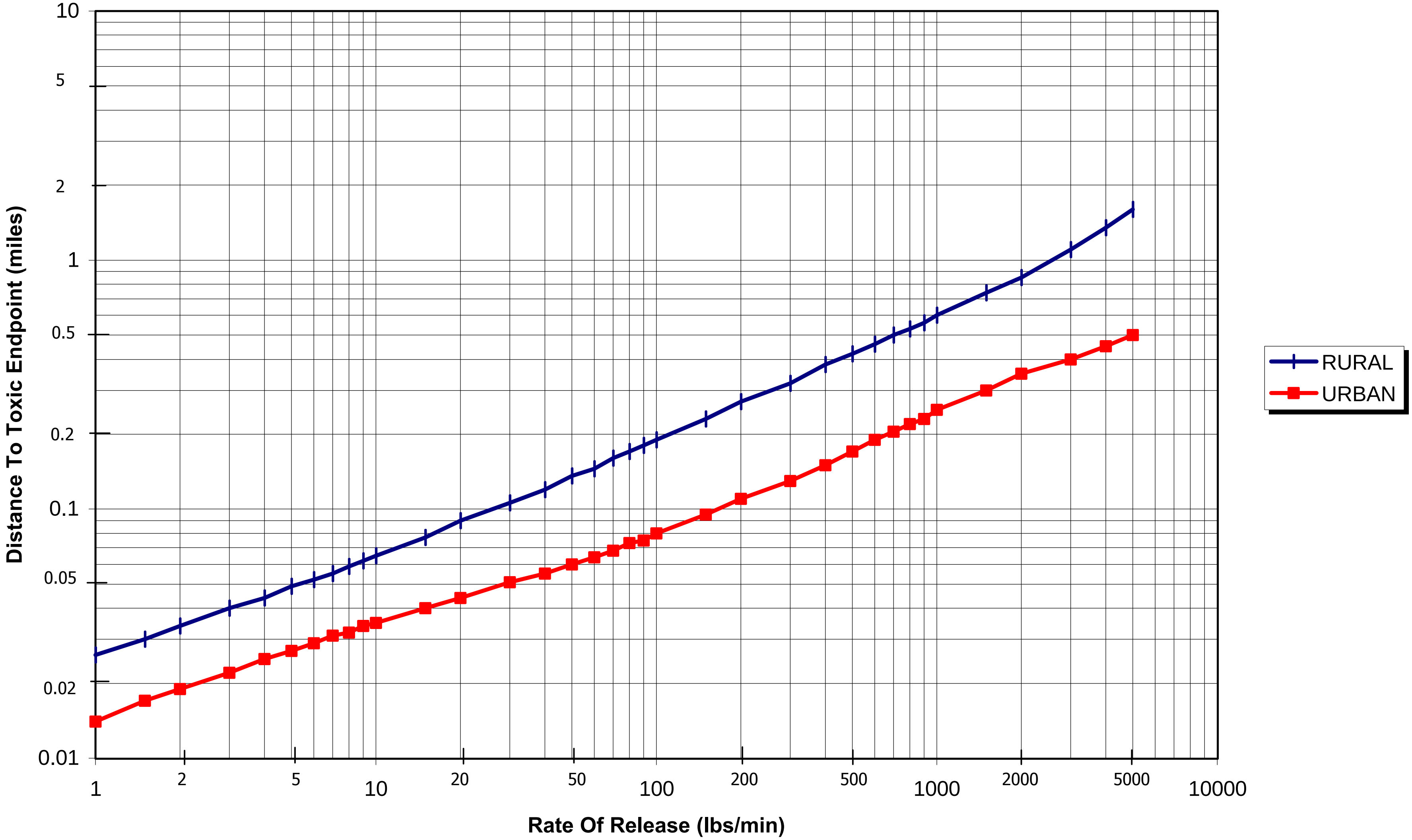


Exhibit 4-6 provides release rates and distances for pressures of 100 to 180 psig and hole diameters of 1/4 inch to 12 inches. (The distances are based on Exhibit 4-5). You may use this exhibit to estimate the distance to the endpoint if this type of scenario is reasonable for your site.

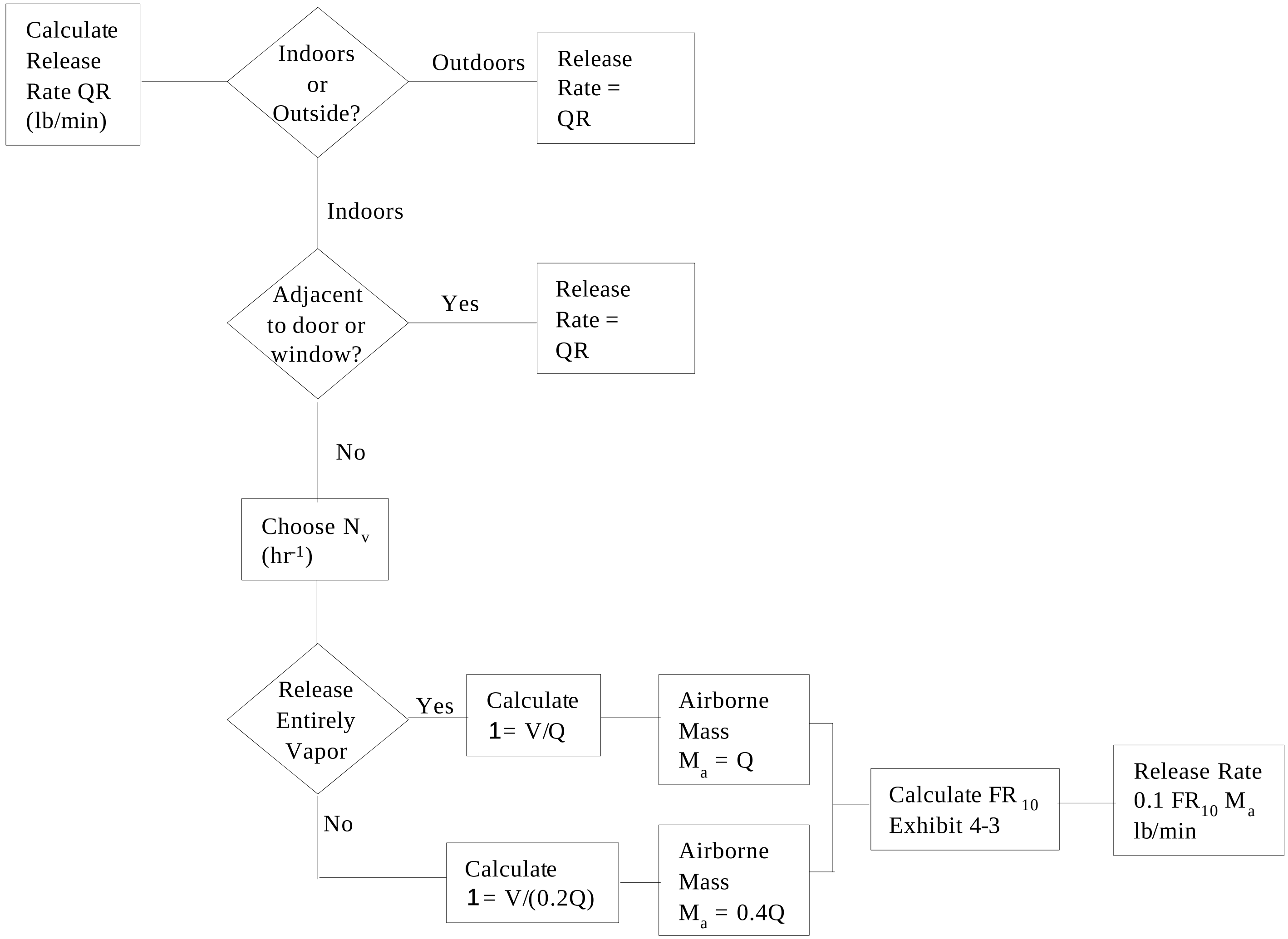
EXHIBIT 4-6
RELEASE RATES AND DISTANCES TO TOXIC ENDPOINT FOR LEAKS OF ANHYDROUS AMMONIA (ALTERNATIVE SCENARIO)

Hole Diameter (inches)	Tank Pressure 100 psig			Tank Pressure 130 psig			Tank Pressure 180 psig		
	Release Rate (lb/min)	Distance (miles)		Release Rate (lb/min)	Distance (miles)		Release Rate (lb/min)	Distance (miles)	
		Rural	Urban		Rural	Urban		Rural	Urban
0.25	100	0.2	0.1	110	0.2	0.1	130	0.2	0.1
0.5	400	0.4	0.2	450	0.4	0.2	540	0.4	0.2
1	1,600	0.7	0.3	1,800	0.8	0.3	2,100	0.8	0.3
2	6,400	1.6	0.5	7,300	1.6	0.5	8,600	1.6	0.5
3	14,300	2.2	0.7	16,400	2.2	0.7	19,300	2.5	0.8
4	25,500	2.8	0.9	29,100	3.1	1.0	34,200	3.1	1.0
5	39,900	3.5	1.1	45,400	3.9	1.2	53,500	3.9	1.2
6	57,400	3.9	1.2	65,400	4.8	1.4	77,000	4.8	1.4
7	78,100	4.8	1.4	89,100	5.4	1.6	105,000	5.4	1.6
8	102,000	5.4	1.6	116,000	5.4	1.6	137,000	6.6	1.9
9	129,000	6.6	1.9	147,000	6.6	1.9	173,000	6.6	1.9
10	159,000	6.6	1.9	182,000	7.6	2.1	214,000	7.6	2.1
11	193,000	7.6	2.1	220,000	7.6	2.1	259,000	8.4	2.3
12	230,000	8.4	2.3	262,000	8.4	2.3	308,000	9.2	2.5

ALTERNATIVE RELEASE SCENARIOS INSIDE A BUILDING

The alternative release scenario inside a building is handled in much the same way as is the worst-case scenario. See Figure 4-4 for a flow chart describing the procedure. To use the factors provided in Exhibit 4-3 for estimating the release rate in a building, you must assume the release takes place over a ten-minute period. The total quantity released will be your estimated release rate multiplied by 10. If a ten-minute release is not a reasonable alternative scenario for your site, you will need to do additional calculations or use a different method for releases in buildings.

Figure 4-4. Guidance on Effectiveness of Building Mitigation for Alternative Scenarios



Example 4 Suppose the release from a ½-inch hole in a tank with pressure 180 psig, cited in Exhibit 4-6, resulting in a release rate of 550 lb/min of flashing liquid ammonia, takes place inside a building with a ventilation rate $N_v = 5\ hr^{-1}$. The release is assumed to take place over ten minutes, and the total quantity released is 550 × 10 = 5,500 lb, of which 0.4 × 5,500 = 2,200 lb becomes airborne. Of the airborne quantity, 1,100 lb is vapor and 1,100 lb is liquid that remains entrained in the vapor. The remaining 3,300 lb of liquid forms an evaporating pool on the floor. The building volume is 50 feet x 20 feet x 20 feet = 20,000 ft^3, so that 1 = 20,000/1,100 = 18 ft^3/lb.

From Exhibit 4-3, FR_{10} = 0.35 for 1 = 25 ft^3/lb (the number closest to 18) and N_v = 5. Assuming a ten-minute release, the rate of release from the building is 77 lb/min [QR_B = (0.35)(0.4)(5,500)/10 from Equation 2 in section 4.1]. Using Exhibit 4-5, the predicted distance to the toxic endpoint is 0.2 mile for a rural site and 0.1 mile for an urban site, compared to 0.4 mile (rural) and 0.2 mile (urban) for the same release outdoors.

As noted above, the attenuation factors in Exhibit 4-3 apply to ten-minute releases. If you want to use the same method to perform a calculation for a different duration of release in a building, consult the Backup Information document cited at the beginning of this chapter for additional information on how to carry out such calculations.

4.3 DEFINING OFFSITE RECEPTORS

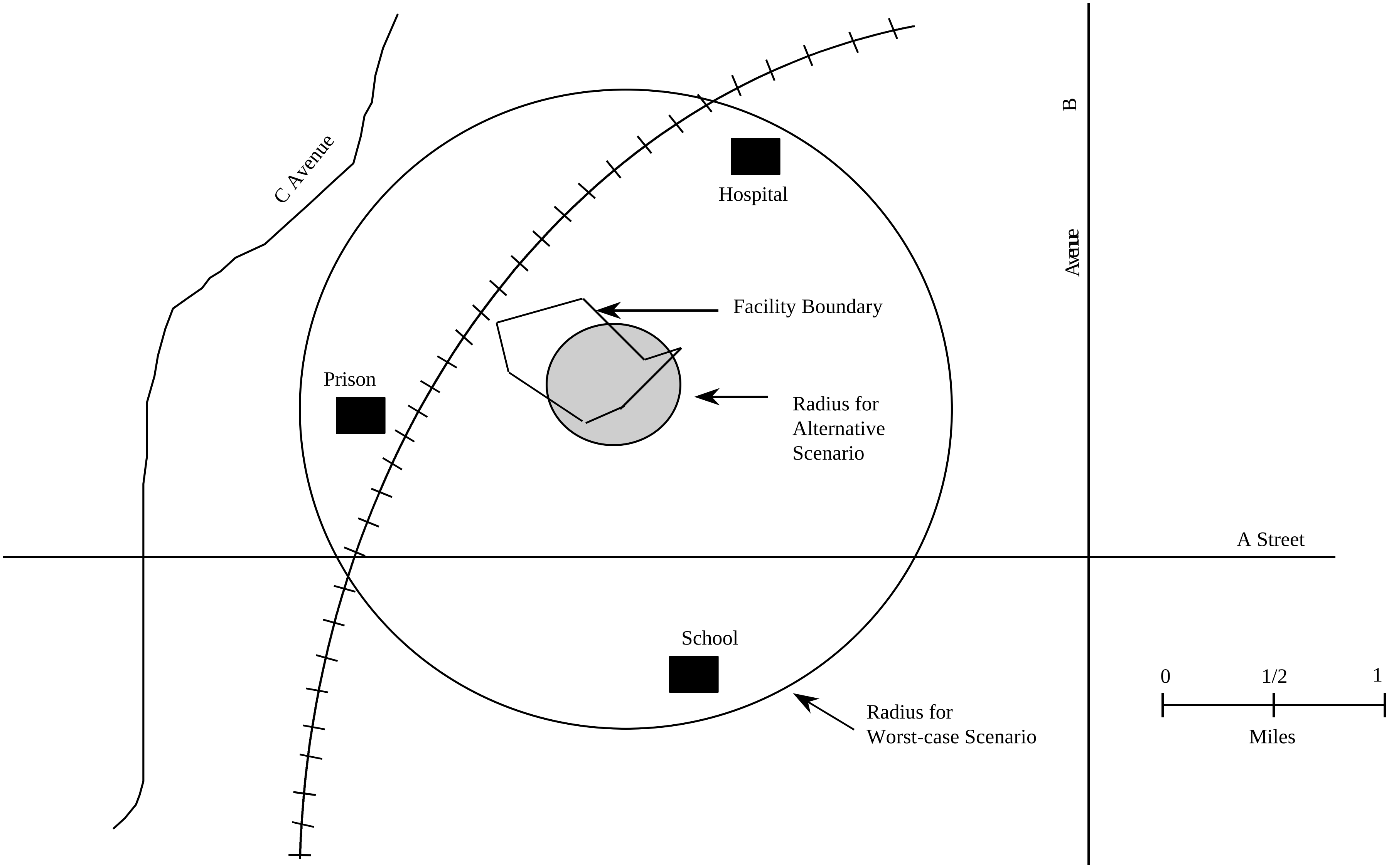
The rule requires that you estimate in the RMP residential populations within the circle defined by the endpoint for your worst-case and alternative release scenarios (i.e., the center of the circle is the point of release and the radius is the distance to the endpoint). In addition, you must report in the RMP whether certain types of public receptors and environmental receptors are within the circles.

Figure 4-5 is one suggested example of how the consequences of worst-case and alternative scenarios might be presented. It is a simplified map that shows the radius to which the vapor cloud might extend, given the worst-case release in worst-case weather conditions (the owner or operator should use a real map of the area surrounding the site).

RESIDENTIAL POPULATIONS

To estimate residential populations, you may use the most recent Census data or any other source of data that you believe is more accurate. You are not required to update Census data or conduct any surveys to develop your estimates. Census data are available in public libraries and in the LandView system, which is available on CD-ROM (see box below). The rule requires that you estimate populations to two-significant digits. For example, if there are 1,260 people within the circle, you may report 1,300 people. If the number of people is between 10 and 100, estimate to the nearest 10. If the number of people is less than 10, provide the actual number.

Figure 4-5 Simplified Presentation of Worst-Case and Alternative Scenario on a Local Map



Census data are presented by Census tract. If your circle covers only a portion of the tract, you should develop an estimate for that portion. The easiest way to do this is to determine the population density per square mile (total population of the Census tract divided by the number of square miles in the tract) and apply that density figure to the number of square miles within your circle. Because there is likely to be considerable variation in actual densities within a Census tract, this number will be approximate. The rule, however, does not require you to correct the number.

OTHER PUBLIC RECEPTORS

Other public receptors must be noted in the RMP (see the discussion of public receptors in Chapter 2). If there are any schools, residences, hospitals, prisons, public recreational areas or arenas, or commercial or industrial areas within the circle, you must report that. You are not required to develop a list of all public receptors; you must simply check off that one or more such areas is within the circle. Most receptors can be identified from local street maps.

ENVIRONMENTAL RECEPTORS

Environmental receptors are defined as natural areas such as national or state parks, forests, or monuments; officially designated wildlife sanctuaries, preserves, refuges, or areas; and Federal wilderness areas. Only environmental receptors that can be identified on local U.S. Geological Survey (USGS) maps (see box below) need to be considered. You are not required to locate each of these specifically. You are only required to check off in the RMP which specific types of areas are within the circle. If any part of one of these receptors is within your circle, you must note that in the RMP.

Important: The rule does not require you to assess the likelihood, type, or severity of potential impacts on either public or environmental receptors. Identifying them as within the circle simply indicates that they could be adversely affected by the release.

HOW TO OBTAIN CENSUS DATA AND LANDVIEW®

Census data can be found in publications of the Bureau of the Census, available in public libraries, including *County and City Data Book*.

LandView ®III is a desktop mapping system that includes database extracts from EPA, the Bureau of the Census, the U.S. Geological Survey, the Nuclear Regulatory Commission, the Department of Transportation, and the Federal Emergency Management Agency. These databases are presented in a geographic context on maps that show jurisdictional boundaries, detailed networks of roads, rivers, and railroads, census block group and tract polygons, schools, hospitals, churches, cemeteries, airports, dams, and other landmark features.

CD-ROM for IBM-compatible PCS
CD-TGR95-LV3-KIT $99 per disc (by region) or $549 for 11 disc set

U.S. Department of Commerce
Bureau of the Census
P.O. Box 277943
Atlanta, GA 30384-7943
Phone: 301-457-4100 (Customer Services -- orders)
Fax: (888) 249-7295 (toll-free)
Fax: (301) 457-3842 (local)
Phone: (301) 457-1128 (Geography Staff -- content)
http://www.census.gov/ftp/pub/geo/www/tiger/

Further information on LandView and other sources of Census data is available at the Bureau of the Census web site at www.census.gov.

HOW TO OBTAIN USGS MAPS

The production of digital cartographic data and graphic maps comprises the largest component of the USGS National Mapping Program. The USGS's most familiar product is the 1:24,000-scale Topographic Quadrangle Map. This is the primary scale of data produced, and depicts greater detail for a smaller area than intermediate-scale (1:50,000 and 1:100,000) and small-scale (1:250,000, 1:2,000,000 or smaller) products, which show selectively less detail for larger areas.

U.S. Geological Survey
508 National Center
12201 Sunrise Valley Drive
Reston, VA 20192
http//mapping.usgs.gov/

To order USGS maps by fax, select, print, and complete one of the online forms and fax to 303-202-4693. A list of commercial dealers also is available at http://mapping.usgs.gov/esic/usimage/dealers.html/. For more information or ordering assistance, call 1-800-HELP-MAP, or write:

USGS Information Services
Box 25286
Denver, CO 80225

For additional information, contact any USGS Earth Science Information Center or call 1-800-USA-MAPS.

4.4 DOCUMENTATION

You must maintain on site the following records on the offsite consequence analyses:

- For the worst-case scenario, a description of the vessel or pipeline selected as worst-case, assumptions and parameters used, and the rationale for selection; assumptions include use of any administrative controls and any passive mitigation that were assumed to limit the quantity that could be released. If the current guidance has been used, Section 4.1 can be referenced as the basis for the choice of the worst-case scenario.

- For alternative release scenarios, a description of the scenarios identified, assumptions and parameters used, and the rationale for the selection of specific scenarios; assumptions include use of any administrative controls and any mitigation that were assumed to limit the quantity that could be released. Documentation includes the effect of the controls and mitigation on the release quantity and rate. Section 4.2 can be referenced here if the "canned" scenario is used.

- Documentation of estimated quantity released, release rate, and duration of release.
- Methodology used to determine distance to endpoints (it will be sufficient to reference this guidance).
- Data used to identify potentially affected population and environmental receptors.

APPENDIX 4A
BRIEF SUMMARY OF THE VARIOUS STATES IN WHICH AMMONIA EXISTS IN A TYPICAL REFRIGERATION FACILITY

A typical block diagram of a two-stage ammonia refrigeration facility is shown on the next page; a similar diagram of a single-stage facility is shown on the following page.

Ammonia Liquefied Under Pressure

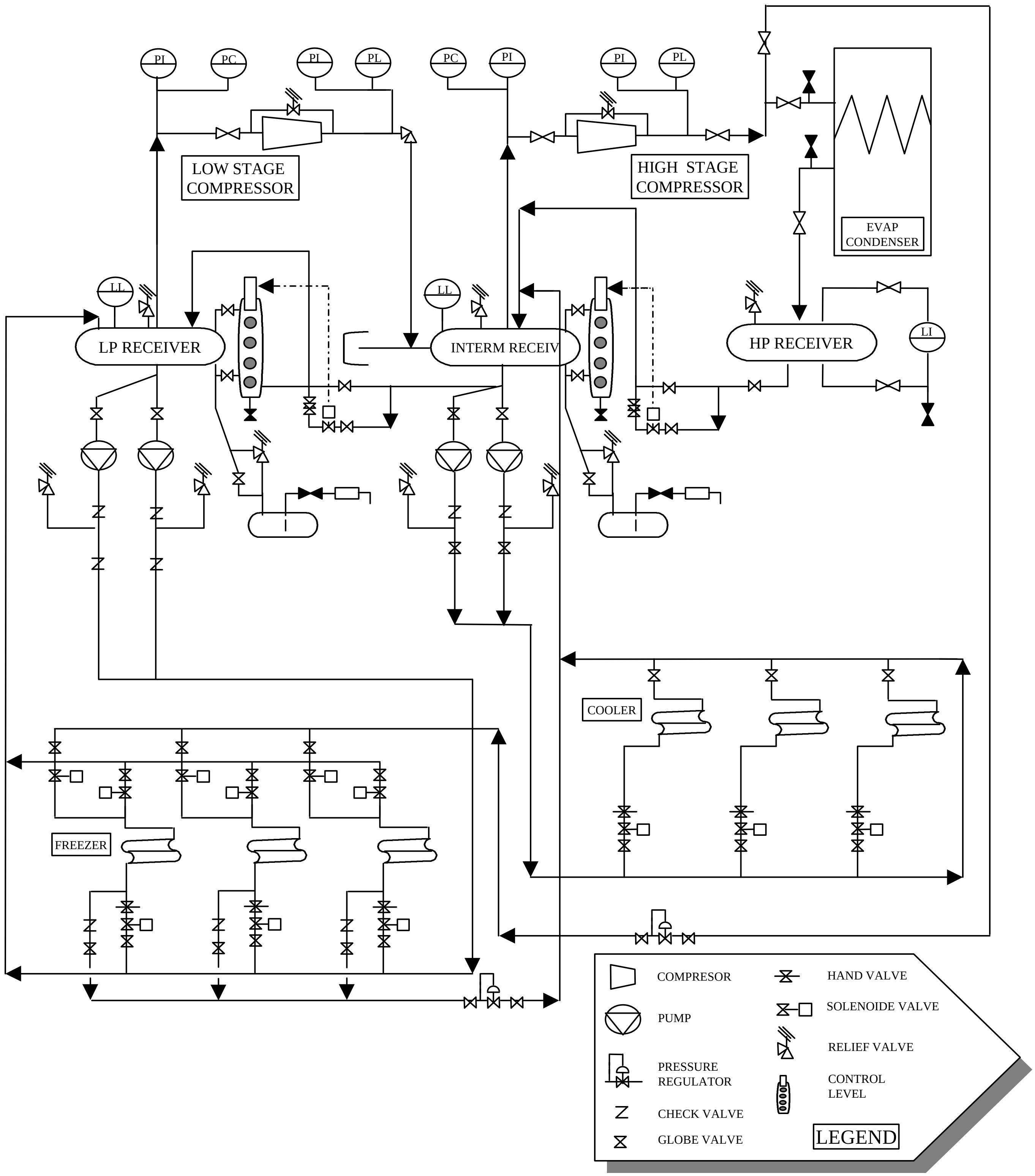
In many parts of a typical refrigeration system, there is ammonia liquefied under pressure. If the pressure and temperature are sufficiently high, and if there is a sudden release of liquid ammonia, it will all become and remain airborne as a mixture of ammonia vapor and very fine liquid droplets that do not fall to the ground, provided that no obstacles are encountered in the immediate vicinity of the release. Experimental results clearly show that this is a real physical phenomenon (Goldwire et al., 1985; Kaiser, 1989). The droplets evaporate quickly as air is entrained. The evaporation process cools the air so that a cold mixture of air and ammonia vapor is formed. The mixture is denser than air, and a heavy vapor dispersion model is required to adequately predict airborne concentrations downwind of the point of release.

In many refrigeration facilities, the ammonia travels from the discharge of the compressors through the evaporative condensers to the high-pressure receiver. The next page shows a range of typical pressures in the high-pressure receiver from 100-200 psig (approximately 8-15 atmospheres). The figure shows ammonia vapor pressure as a function of temperature. Pressures of 8-15 atmospheres correspond to ammonia temperatures of approximately 10-40 °C, or superheats (number of degrees above the atmospheric boiling point) of about 40-70 °C. These conditions are definitely such as to ensure that all of any liquid ammonia release will become and remain airborne.

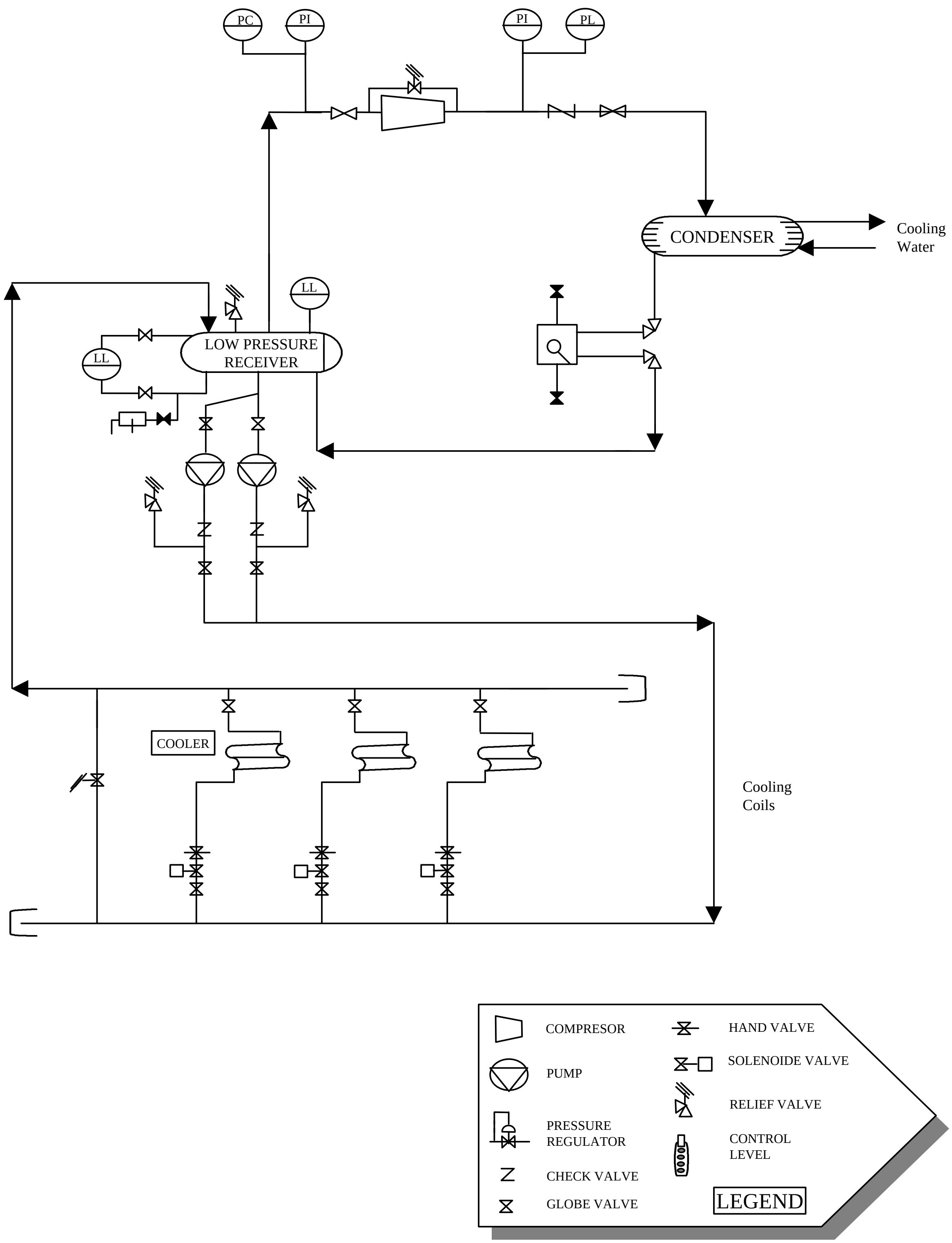
Some (but by no means all) refrigeration facilities have an ammonia storage vessel in addition to the high-pressure receiver. This vessel will, in all likelihood, be outside, and its pressure will fluctuate with the external temperature. However, at an ambient temperature of (say) 25 °C, the superheat would be about 60 °C so that the characteristics of any release from such a vessel are expected to be similar to those of a release from the high-pressure receiver. A release from such a vessel should be considered as a candidate for the worst case.

Some refrigeration facilities may not have a high-pressure receiver. In such facilities, ammonia at pressures as high as 180 psig is confined to pipework, and there may be a low-pressure receiver with a typical pressure in the range 10-60 psig (~ 2-5 atmospheres), also containing ammonia liquefied under pressure. From Figure 4-A.1, the corresponding temperatures are -20-0 °C, or superheats of 10-30 °C. It is only slightly conservative to assume that all of the ammonia released from such a vessel becomes airborne. Two-stage systems have an intermediate receiver, which has a range of operating pressures similar to those for low-pressure receivers in a single-stage system.

Two-Stage Ammonia Refrigerating System



Single-Stage Ammonia Refrigeration System with High-Side Float Regulator and Pump Circulation



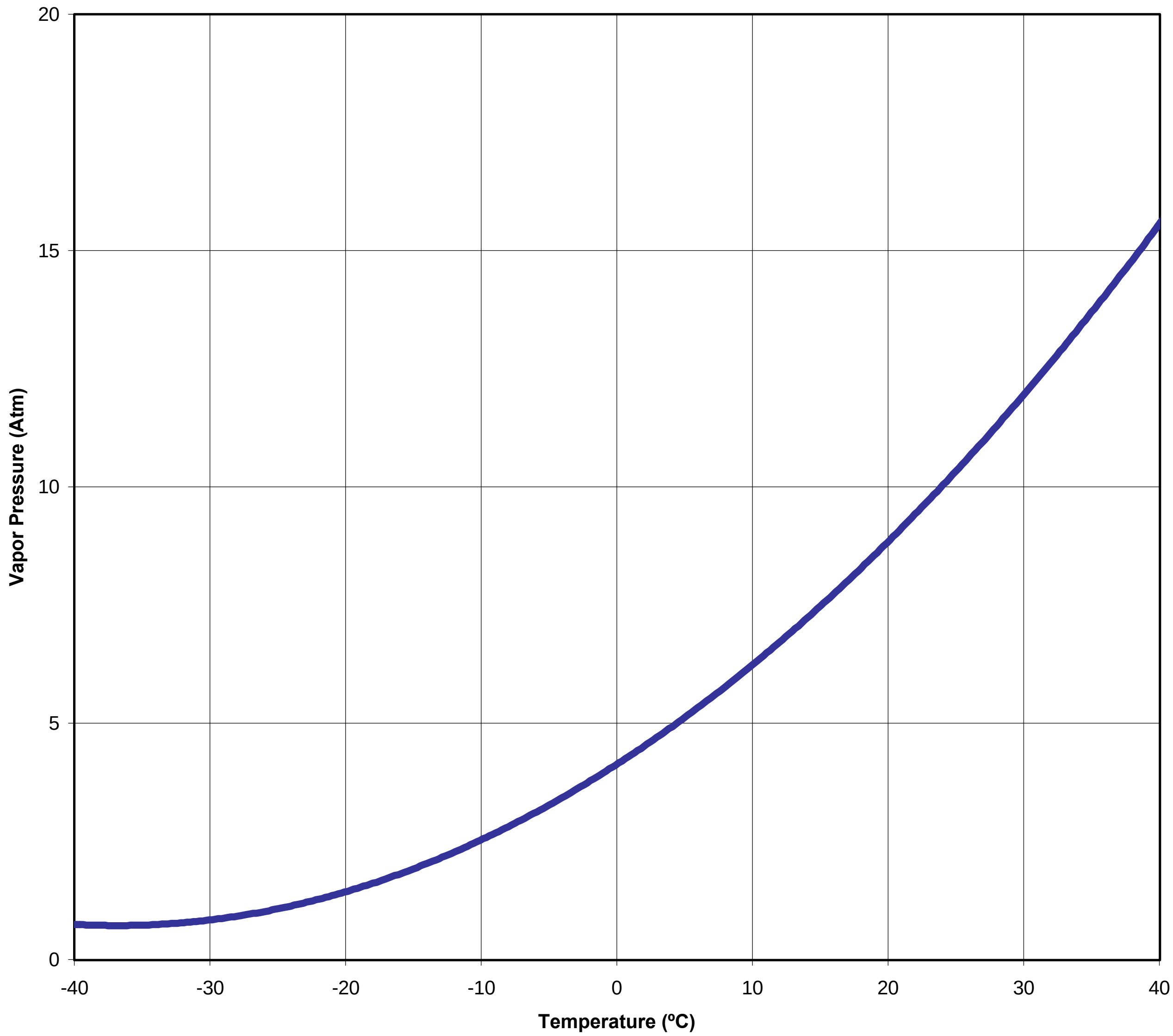
Ammonia at Subatmospheric Pressures

In some facilities (e.g., food processing plants), even colder ammonia may be needed (when, for example, very rapid freezing of food is necessary). The first figure shows a low-pressure receiver with subatmospheric pressures as low as 15 inches of water, which corresponds to a temperature well below the atmospheric boiling point. If released, the ammonia will spill onto the ground and, over an average period of 10 minutes or more, will evaporate at a much lower rate than a release from a worst-case rupture in such a vessel as the high-pressure receiver. In addition, these low temperature vessels are generally inside buildings, and it is likely that this would further reduce the effective rate of release to the atmosphere external to the refrigeration plant.

Ammonia Gas

Finally, in ammonia refrigeration systems there is ammonia gas (vapor) in the system under a range of temperatures and pressures. If there is a rupture in the vapor space of the high-pressure receiver (say), there will be a buoyant ammonia jet (i.e., the ammonia vapor is less dense than air). However, for a given hole size and a given pressure, the rate of release of ammonia gas is very much less than that of liquid ammonia, so that it is unlikely that a vapor release would be the worst-case.

Figure 4-A-1 Vapor Pressure of Ammonia as a Function of Temperature



APPENDIX 4B
EQUATIONS FOR LOG-LOG GRAPHS AND CALCULATIONS

LOG-LOG EQUATIONS

The guidance on Figure 4-2 is essentially in the form of a straight line on a log-log plot:

$$D = 0.0607(QR)^{0.4923} \tag{B-1}$$

for a rural site and

$$D = 0.0443(QR)^{0.4782} \tag{B-2}$$

for an urban site, where:

D	=	Distance to the endpoint (miles)
QR	=	Release rate (lb/min)

If you wish, you can use Equation 1 or 2 instead of Exhibit 4-4 or Figure 4-2.

The curves on Figure 4-3 are approximately straight lines on a log-log plot:

$$D = 0.0222(QR)^{0.4780} \tag{B-3}$$

at a rural site, and

$$D = 0.0130(QR)^{0.4164} \tag{B-4}$$

at an urban site.

If you wish, you can use Equation 3 or 4 instead of Exhibit 4-5 or Figure 4-3.

ALTERNATIVE RELEASE SCENARIOS

There are many possible alternative scenarios. Some of those identified from a review of past incidents in refrigeration facilities (see Appendix 4C) include:

- Plant upsets leading to the lifting of relief valves
- Pipeline failures
- A blocked-in, liquid-full pipeline rupturing as it heats up
- Failures during ammonia delivery, such as a hose leak

The rule states that other scenarios, listed in Section 4.2, should be considered

In addition, active and passive mitigation systems may be considered, provided that they can be shown to withstand the cause of the release.

It is apparent that there is a great variety of alternative scenarios. However, EPA requires that only one such scenario be identified and modeled. Many scenarios are effectively equivalent to a small hole of diameter ¼ inch to ½ inch (e.g., a gasket rupture or a pump seal leak). Remember, however, that the alternative scenario must result in offsite consequences, unless you can show that no such scenario exists.

The rate of release QR for a liquid release through a hole may be calculated using Bernoulli's formula:

$$QR = cD_L A(2P_g/D_L + 2gh)^{0.5} \quad \text{(B-5)}$$

where:

c	=	a constant (typical value 0.8)
D_L	=	the density of the liquid in the vessel (639 kg/m^3 for ammonia)
A	=	the area of the hole (m^2)
P_g	=	the gauge pressure in the vessel (Pa)
g	=	the acceleration due to gravity (9.82 m/s^2)
h	=	the static head (m)

The static head is likely to be negligible when the tank pressure is high, as is likely for liquefied ammonia; therefore, the 2gh term in Equation B-5 can be ignored.

The following equation drops the 2gh term and includes conversion factors:

$$QR = 132.2 \times 6.4516 \text{ x } 10^{-4} \times 0.8 \times 639 \times a)HA \times (2 \times (P_g/639) \times 6895)^{½} \quad \text{(B-6)}$$

. where:

QR	=	Release rate (pounds per minute)
HA	=	Hole area (square inches)
132.2	=	Conversion factor for kilograms per second to pounds per minute
6.4516 x 10^{-4}	=	Conversion factor for square inches to square meters (*HA*)
0.8	=	Discharge coefficient (0.8)
639	=	Liquid density of ammonia (kg/m^3)
P_g	=	Gauge pressure in tank (psi)
6,895	=	Conversion factor for psi to Pascals (P_g)

Combining the conversion factors and incorporating the density of ammonia, leads to the equation presented in the text as Equation 2 for the release rate through a hole of ammonia liquefied under pressure:

$$QR = 203 \times HA \times (P_g))^{½}$$

Note that this is the formula for the release of a pure liquid and would apply to a breach in the wall of a vessel or to the rupture of a very short pipe. For long pipes, there is a pressure drop between the vessel and the hole that leads to flashing in the pipe and a reduced rate of release

The scenario needs to be modeled in typical weather conditions. For many sites, Atmospheric Stability Category D with a moderate wind speed (e.g., 3 m/s) is close to average. The distance to the toxic endpoint can then be estimated from Figure 4-3 or from Exhibit 4-5, which is a tabulation of Figure 4-3. These results could simply be quoted in the Risk Management Plan.

You also may identify your own alternative scenario(s). Consult your trade association (e.g., the International Institute of Ammonia Refrigeration) for guidance on other scenarios. Your Process Hazards Analysis is another potential source of pertinent information. However, remember that the regulation requires that releases large enough to have the potential to exceed the toxic endpoint offsite be considered.

GENERAL GUIDANCE ON MODELING

If you decide to perform your own modeling, you must carefully consider two major items:

(a) Correct characterization of the source term[1]
(b) Choice of a suitable dispersion model

The quadrennial conferences on vapor cloud dispersion modeling that are organized by the Center for Chemical Process Safety (CCPS) are a good source of information on the latest developments in source term and dispersion modeling (CCPS, 1987, 1991, 1995). There are also CCPS Guidebooks, such as "*Guidelines for Use of Vapor Cloud Dispersion Models - Second Edition".*

EPA has also published guidance. There is one document that looks carefully at the definition of source terms (USEPA, 1993). EPA has also performed an evaluation of dense gas dispersion models (USEPA, 1991). Another review of available models has been given by Hanna et al. (1991).

REFERENCES FOR APPENDIX 4B

Brighton, P.W.M. (1989). "Pressures Produced by Instantaneous Releases of Chlorine Inside Buildings," United Kingdom Health and Safety Executive Report SRD/HSE/R467, Her Majesty's Stationery Office, London.

Center for Chemical Process Safety (CCPS, 1987). *"Proceedings of the International Symposium on Vapor Cloud Modeling,"* Boston, MA; American Institute of Chemical Engineers, New York, NY.

Center for Chemical Process Safety (CCPS, 1991). *"International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials"* New Orleans, LA; American Institute of Chemical Engineers, New York, NY.

Center for Chemical Process Safety (CCPS, 1995). *"International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental releases of Hazardous Materials,"* New Orleans, LA; American Institute of Chemical Engineers, New York, NY.

Goldwire, Jr., H.C., T.G. McRae, G.W. Johnson, D.L. Hipple, R.P. Koopman, J.W. McLure, L.K. Morris and R.T. Cederwall (1985). "Desert Tortoise Series Data Report - 1983 Pressurized Ammonia Spills," Lawrence Livermore National Laboratories Report UCID-20562, Livermore, CA.

[1]A "source term" is the source information for the atmospheric dispersion model and is characterized by the rate of release, the duration of release, temperature, density, momentum, aerosol content, etc.

Hanna, S.R., D.G. Strimatis and Joseph C. Chang (1991). "Uncertainties in Hazardous Model Gas Predictions," in CCPS (1991), pp. 345-368.

United States Environmental Protection Agency (USEPA, 1991). *"Evaluation of Dense Gas Simulation Models,"* EPA-450/R-89-018, Research Triangle Park, NC.

United States Environmental Protection Agency (USEPA, 1993). *"Contingency Analysis for Superfund Sites and Other Industrial Sources,"* EPA-454/R-93-001, Research Triangle Park, NC.

APPENDIX 4C
INFORMATION ABOUT ACCIDENTAL RELEASES OF AMMONIA

For a number of years, EPA has been keeping a record of accidental releases in the Accidental Release Information Program (ARIP). Considerable information is requested of those who have reportable releases.

The database has numerous entries recorded since its inception, many of which involve ammonia. A list of all events involving ammonia refrigeration plants, which resulted in an offsite release was obtained. The original report of each of these events was examined for root cause, as described by the reporting firm. Other information on the reports was also considered. In some cases, there were multiple applicable root causes.

In the examination of the data, a comparison of the event to the elements of the Prevention Program was made. The elements of the Program, which, had they been properly carried out, would have prevented the release, were judged to be the root causes.

The data garnered from this examination reveal that several sub-elements of Mechanical Integrity are vital to preventing releases from ammonia refrigeration plants. In particular, a majority of the accidents have omissions in inspections or tests as a root cause of the releases.

These data are presented in the spreadsheet that follows.

ARIP No.	Event	Operation	Root Cause	Process	Remarks
4153	Valve disassembled	Maintenance	Contractor selection	Public CS	Error in installing a new accumulator
1770			E/R training	Ice cream	Equipment upgrade stated
2579			E/R training	Food production	Sched 40 thd pipe used instead of welded sch 80
2825			E/R training	Poultry processing	Procedure produced untenable thermal shock
1281	Flange blew out	In operation	M.I. fit for purpose	Citrus concentrate	Cast iron flange
2850	Condenser leak	Maintenance	M.I. inspection	Milk	Corrosion; new unit on order at the time
1078	Heat exch. leak	In operation	M.I. inspection	Ice mfg.	Ice machine tube failure
1080	Valve failure	In operation	M.I. inspection	Meat process	No explanation
1338	Pipe joint failure	In operation	M.I. inspection	Milk & ice cream	Fatigue failure on vibration
1901	Valve separation	In operation	M.I. inspection	Food processing	Corrective actions inspection and maintenance
4140	Gasket leak	In operation	M.I. inspection	Ice	Gasket leak on compressor; shut off valve failed to close
4209	Recip shaft seal	In operation	M.I. inspection	Frozen fish	Main brg. failure - broken crank
3320	PRV opens	Maintenance	M.I. inspection	Ice	In pressure test to less than stated relief pressure; opened at lower pressure
1394	Pipe break	Sched shutdown	M.I. inspection	Ice cream	Equipment upgrade stated
834	Pipe broke	Temp inactive	M.I. inspection	Turkey prod.	None given; Corr. Actions were Inspections; RC inferred
2320	Tube rupture	Temp inactive	M.I. inspection	Frozen juices	Condenser replaced with new design
4269	PRV opens	Temp shutdown	M.I. inspection	Ground beef	Data missing
2456			M.I. inspection	Public CS	Solenoid valve fails to close
1770	Tube rupture	In operation	M.I. inspection (Inf)	Ice	Inspection called out
2202	Valve leak	Sched shutdown	M.I. inspection (Inf)	Frozen desserts	Correction actions PM, inspection and test
2825	Valve came apart	In operation	M.I. procedures	Poultry processing	Procedure produced untenable thermal shock
2227	PRV opens	Maintenance	M.I. procedures	Poultry	Equipment not tied into central controller; restarted improperly after maintenance
424	Sight glass leak	Weekend shutdown	M.I. procedures	Sausage mfg.	Contractor left compressor water off
2456	Pipe break	In operation	M.I. QC	Food production	Sched 40 thd pipe used instead of welded sch 80
4252	Pump casing worn	Maintenance	M.I. QC	Distribution whse.	Pumps replaced with a “more reliable design”
1879	Strainer casting	In operation	M.I. QC (Inf)	Meat processing	Strainer casting failure; changed design
799	PRV opens	In operation	M.I. test	Public CS	Ice buildup; fan destroyed; high-pressure cutout fails
2332	PRV failure	In operation	M.I. test	Citrus juices	RV neither tested nor replaced
2340	PRV opens	In operation	M.I. test	Public CS	Solenoid valve fails to close
1098	PRV opens	In operation	M.I. test	Cheese	RV set pressure less than high-pressure trip; would not reseat
1878			M.I. test	Ice	Inspection called out
1878	Unit failure	In operation	PHA	Meat processing	Improved control at PLC called out
2579	Pipe cap blown off	In operation	PHA	Poultry processing	Procedure produced untenable thermal shock
2907	PRV opens	In operation	PHA	Public CS	Not stated; vent re-routed to accumulator
3218	PRV opens	Normal startup	PHA	Cheese	Failed to start water pump on startup
453			PHA	Sausage mfg.	Contractor left compressor water off
1098			PHA	Cheese	RV set pressure less than high-pressure trip; would not reseat
2227			PHA	Poultry	Equipment not tied into central controller; restarted improperly after maintenance
3263	Pipe break, forklift	In operation	PHA (siting)	Meat packing	Exposed piping - to be rerouted
3539	Piping damage	In operation	PHA (siting)	Beer	Damaged ammonia piping; PHA called out as corrective active
453			Procedures	Sausage mfg.	Contractor left compressor water off

ARIP No.	Event	Operation	Root Cause	Process	Remarks
1106			Procedures	Cheese	RV set pressure less than high-pressure trip; would not reseat
3218			Procedures	Cheese	Failed to start water pump on startup
1106	Open line	Construction	PSSR	Public CS	New construction; valve left uncapped at startup
3090	Valve left open	Startup new equip	PSSR	Meat products	No check for proper installation prior to startup
4170	Not legible	Startup new equip	PSSR	Not legible	Details illegible
3538	Valve left open	Maintenance	SWP	Beer	Valve left open during maintenance
453	Flex joint break	Temp inactive	Training	Veg. mfg.	Trapped liquid; operator error; design fault